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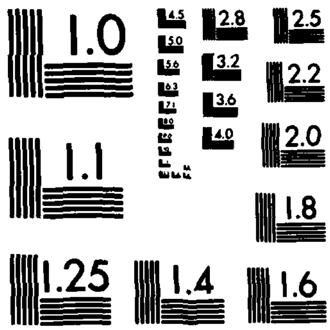

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

DIGITAL TRANSMISSION IN MOBILE ULTRASHORTWAVE COMMUNICATIONS

by

Aleksy Pankow

FOREIGN TECHNOLOGY DIVISION

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DIGITAL TRANSMISSION IN MOBILE ULTRASHORTWAVE COMMUNICATIONS

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Mobile ultrahigh frequency radio communications, that is, ultrahigh frequency radio communications with objects moving on land or inland waters, constitutes an important element in the general information system of a society. The role played by UHF mobile communications increases commensurately with the increase in its range and level of its services. In the beginning, mobile communications networks were characterized by their very simple structure. They were developed mainly as dispatcher-type networks. This period was characterized by a rapid increase in the number of equipment, which was accompanied by some engineering progress, both in the field of systems and basic equipment parameters. Applicatio s of the achievements of the "semiconductor revolution" made it possible to achieve considerable miniaturization, reliability, and a high degree of watt-hour efficiency of equipment in radio communications.

The next development stage was characterized by a more serious approach to problems related to planned assignment of the frequency spectrum. This was due to considerable overloading of frequency ranges assigned to mobile UHF radio communications services. The basic steps taken to surmount difficulties involving waves included a spatial subdivision of frequency channels on a

country-wide and international scale, more stringent requirements on technical parameters of the equipment, planned assignment of new frequency ranges, more efficient utilization of communications channels by forming multichannel network centers. In recent years, pronounced qualitative changes have taken place in mobile UHF radio communications. Theoretical studies, scientific research, and implementation studies are being conducted on a wide scale, the purpose of which is the development of future promising mobile radio communications systems that are integrated both with automated telephone networks and remote data transmission networks. It is obvious that such systems can only be fully automated systems allowing the transmission of analog and discrete signals. The possibilities and prospects for digital transmission in mobile communications networks are especially interesting in this aspect.

Until now, not enough light has been shed on this problem in the domestic literature. To some extent, this clarification is the purpose of this article.[1]

It appears that among the many advantages in the development of digital transmission, some of the basic ones are:

- possibility of more efficient organization of communications systems and greater efficiency of systems proper;

- high likelihood of transmitting information and possibility of documenting transmitted text;

- practically unlimited possibilities for secrecy of transmitted information;

- possibility of interacting with stationary remote data transmission systems;

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[1] This article is based on materials published in the report announced by the author at the symposium "Remote Data Transmission Networks", Gdansk, 1975.

- high interference immunity;
- possibility of transmitting information in the absence of subscriber.

At the present time, three basic directions can be singled out in the development of digital transmission techniques in mobile communications networks:

1) transmission of discrete signals as an element in automation of radiotelephone communications systems;

2) transmission of information in digital form, including:

a) transmission of programmed information (with limited content);

b) exchange of any alphanumeric data among subscribers of a network by the teleprinter method;

c) access to and communication with computerized data bases;

3) replacement of analog transmission of speech signals by discrete transmission.

The above-mentioned directions will be briefly discussed in the following part of the article.

Digital transmission as an element of automation of radiotelephone communications systems

A more efficient utilization of radio channels assigned to mobile communications services can be achieved, among other ways, by automating the operation of systems. The basis for automation is generation and transmission of appropriate signals, manipulation or control signals, between stations constituting a part of the communications system. In this manner, digital signals appear in the ether, besides sound signals.

The first step towards automation of communications in mobile networks was selective calling. Generally speaking, selective calling involved lockout of the output of stages of radiotelephones operating in a given network, among

which only that station is unlocked to which a special signal is directed. Three basic selective calling systems are distinguished, which are based on the following codes: frequency (parallel) code, time-frequency (serial code), and pulse code. The advantages and shortcomings of individual codes used in selective calling systems have been discussed in detail in the literature [1]. The only point that needs to be emphasized is that research conducted both in the country and abroad on the comparison of selective calling systems, from the standpoint of their calling reliability and interference immunity, has shown that serial time-frequency code is most suitable for mobile UHF communications purposes. This code has been recommended for use in the country [2].

The next step in improving operational efficiency in mobile communications networks was the introduction of *automated identification of the mobile subscriber*. The operational principle of the identification system involves the following: each time the transmitter is turned on in order to establish communication with the base station, a digital signal identifying the given mobile station is transmitted automatically. At the base station the received signal is displayed on a CRT display or recorded. The time the radio channel is busy and the time the operators at the mobile station and the base station are busy is reduced at the same time in this manner.

The code used in the identification system is predominantly analogous to the selective calling system code. This simplifies considerably the design of equipment in case both systems are used in the network.

The identification system of the mobile subscriber also allows simultaneous transmission of additional information. This possibility is attained as a result of using only a part of the digital combinations, for example, five digits out of ten. The remaining digits are used to transmit any information pertaining, for example, to the position of a vehicle, need for help, etc. Such a system has been developed by the Storno Company (MI system).

In Poland a mobile subscriber identification system based on a time-frequency code has been developed in the Industrial Telecommunications Institute and applied

in domestically manufactured radiotelephone equipment (ZR RADMOR and WZR WAREL). Among other systems, it is operating together with the alarm system, in the Warsaw taxi fleet radiotelephone network.

Automated location of the position of a mobile station with the aid of digital transmission can be acknowledged to be the next step toward automation in identification. It is an important means of improving the operational efficiency of the network of law enforcement agencies, of taxi, city communications, etc. Several concepts of systems for locating the position of a subscriber are known, which differ considerably from one another by their operational principle [3]. Generally such systems are very expensive and great investments are required to put them into operation.

A system designed to satisfy the requirements for police services in Washington can be included among the simpler, therefore less expensive systems [4]. The operational principle of the system is based on the known location of the stationary receivers situated within the area in which the network operates. Each vehicle is equipped with a low-power transmitter (range: 60 m) emitting continuously the identification signal of the given station. In accordance with the design, stationary radio receivers are located in street boxes to meet the needs of the inhabitants of the city for direct telephone communications with the police exchange. The latter can also be placed in fire alarm boxes, in boxes controlling traffic lights, etc. The location system accuracy depends on the possibility available for distributing receivers over the terrain of a city. Fig. 1 presents schematically the operational principle of the location system. The new element here is the inclusion of a computer controlling the operation of a system. Identification signals from mobile transmitters are transmitted from individual receivers in the terrain via two-wire circuits (special or intracity telephone circuit) to terminal (group) equipment, where each piece of equipment provides service to a particular zone in the city. Fig. 2 presents the block diagram of the terminal equipment. The information signal in pulse form is transmitted to the processor from the group equipment. This signal together with the precise arrival time is recorded in disk memory. The system allows the operator to determine immediately the position of each vehicle or to ascertain which vehicle is nearest a particular place.

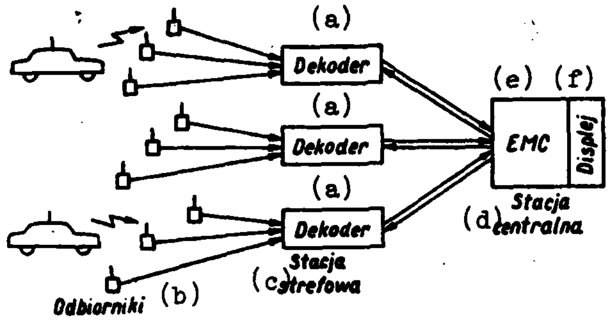

Fig. 1. Operational principle of location system

Key: a. Decoder b. Receivers c. Zone station
d. Central station e. Electronic computer
f. Display

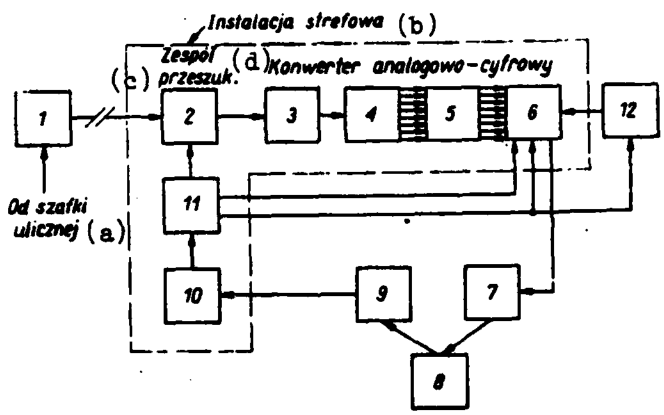

Fig. 2. Zone station of location system:
1 - box terminal 2 - multiplexer 3 - amplifier and limiter 4 - system of filters 5 - demodulator
6 - recorder 7,9 - modems 8 - computer terminal
10 - programming unit 11 - control unit
12 - strobing generator

Key: a. From street box b. Zone installation
c. Search unit d. Analog-to-digital converter

The location system developed by GTE Sylvania is operating on yet another principle [5]. Information about the position of the vehicle is contained in the signal transmitted by the driver (together with the identification signal). A special matrix encoder, a flat plate covered by the map of

the area, generates the location signal. To each point in the plane a particular encoding signal is assigned, which is a function of the coordinates of the matrix. The encoder is actuated by touching with the finger the plane of the map at the point defining the position of the vehicle. The encoded signal is transmitted in digital form directly to the base station and from the latter to the dispatcher center, where it is displayed on a special map and recorded in memory. The identification number of the radio-equipped vehicle is displayed simultaneously.

Digital technology has been widely applied in equipment and systems for automatic connection of VHF radio networks with telephone networks, in particular, in multichannel systems with automatic search of an unoccupied radio channel. The radiotelephone exchange plays the main role in such a system. The equipment of a mobile station must include, besides the selective call, identification and a free radio channel search system (in a multichannel network), also systems which make it possible to transmit signals selecting the number of a telephone network subscriber. The task of the radiotelephone exchange is to establish automatically connections, to recode selection signals from a mobile station and to transmit them to the telephone exchange, and to control the operation of the base radiotelephone. Various versions of the engineering design of a radiotelephone exchange are possible, which depend, above all, on the manner in which communications are organized in the system, or on the method used for access to the free channel. One possible version of a radiotelephone exchange is a concept that has been elaborated in the Industrial Telecommunications Institute in Warsaw [3].

An example of a system realized in practice, where the radio network constitutes a natural extension of the intracity telephone network, is the eight-channel automatic SMART radiotelephone communications system developed by the Storno Company. The drawback of this system is its limited operational range. The mobile station collaborates here only with one base station, exclusively in its operating range. To increase the operating range of the network, a system must comprise many base stations. To avoid mutual interference, neighboring base stations must operate at various frequencies, while every mobile station must possess all channels available in the latter to be able to collaborate with all stations. This leads to a considerable expansion and higher

costs of mobile equipment in the case of a conventional multichannel design, since it also suggests basing the design of the radiotelephone on digital frequency synthesis. A multizone extension of a mobile communications network makes it necessary to introduce centralized commutation of base stations belonging to the network in order to switch over conversations taking place between mobile and stationary subscribers at the instant when the mobile subscriber crosses the boundary separating the zones of individual base stations. The necessity arises of locating continuously the position of the mobile subscriber and connecting the location system with the system controlling the communications network. Present trends in the world follow these lines and the predominance of systems with small areal base zones (in view of more efficient utilization of channels) has been demonstrated theoretically [6].

Data transmission in mobile UHF communications networks

From the beginning of its development, the analog system for transmitting information based on amplitude or frequency (phase) modulation of the carrier signal containing information that is basically a sound signal was dominant in mobile UHF radio communications. To improve the operational quality of mobile communications, systems and devices constituting the beginnings of digital transmission have been gradually introduced, which fulfilled a service function in relation to the basic task of the system--making possible a direct exchange of information between users of the networks (subscribers). Such systems (as for example, the selective calling, identification of a subscriber, location of a vehicle, and other systems) have been discussed above. The application of coding signals in mobile communications networks, performing auxiliary functions, accelerated the introduction of information exchange in digital form in these networks. One can observe an increasingly faster rate at which digital transmission systems are being introduced in mobile UHF radio communications. Digital transmission, which is to be interpreted here as the exchange of information between subscribers (or between a subscriber and a data source) in digital form, does not cover the case of digital sound transmission (or the transmission of sound information in discrete form). In this sense, it is more similar to "classical" data transmission. Problems involving digital sound transmission will be discussed below.

Data transmission systems used at the present in mobile UHF radio communications can be classified as follows:

1) Systems in which terminals hold a strictly limited (predetermined) amount of information. In principle, this information is of fundamental importance, frequently repeated or requiring urgent transmission. In these kinds of systems, besides digital transmission of basic information, sound transmission is also used because of the limited amount of digital information, the main exchange carrier. An example of a solution is the system used in the public transportation network in Goteborg (Sweden) developed by the Storno Company. To a certain extent, some of the systems discussed above, for example, the automated mobile subscriber identification system, the automatic alarm, or location of position system can be included among systems of this kind from the standpoint of the information content of the transmitted signals.

2) Systems in which terminal equipment comprising teleprinter attachment and (predominantly) a CRT display are connected to radio equipment, which makes possible the exchange of any alphanumeric data between mobile subscribers and dispatcher points. Sound transmission used in these systems besides digital transmission is relegated to an auxiliary function. An example of such a system is the system introduced in the taxi fleet in New York or systems used by police in some American cities (utilizing terminal equipment of the MCT-10 type manufactured by the Kustom Electronics company or the Vp-1000 type manufactured by the Motorola Company).

3) In the third kind one can include mobile communications systems whose users have a technical capability to interact with industrial branch or government data transmission telecommunications networks, connected data processing and electronic computer centers, or appropriate computer files. The opertion of such systems is usually computer-controlled. They are being developed at the present time in the United States, mainly in police services.

From the standpoint of technical progress in mobile radio communications networks, at the present time the systems mentioned in item 2 may be of greatest importance, i.e., systems making possible transmission from and to mobile

subscribers, besides conversations, alphanumeric data in the form of discrete signals. Clearly, these systems can be developed along lines which will include them in stationary remote data transmission networks. Equipping mobile subscribers with alphanumeric terminal equipment of the teleprinter type ensures documentation of information received while traveling or in the absence of a subscriber of a mobile station. Besides the advantages of digital systems that have already been mentioned, such as greater speed and more reliable transmission of information compared with sound systems, the possibility of documenting the information, the much higher degree of secrecy, interaction with computer systems, their application also improves traffic safety.

At the present time, several designs of mobile alphanumeric terminal equipment are being offered in the American market, for example, MCT-10, manufactured by the Kustom Electronics company, IBM 2976 terminal equipment, the keyboard attachment manufactured by the Xerox company, or the alphanumeric keyboard attachment to the Digicom-300 system manufactured by the Sylvania company. Motor vehicle alphanumeric printers intended for interaction with radio equipment operating in mobile networks, for example, of the Vp-100 type manufactured by the Motorola company, have also been developed [7].

Such terminals were admitted for test use in the U.S. by the FCC decision on 9 May 1972. Type Vp-100 printers were installed, among others, in 418 police radio cars in the state of California as part of the complex communications system for law enforcement agencies in this state realized by the radio communications department of the Motorola company. The MODAT computer was used in this system. After three years of preparations, this system has been introduced in operation in June, 1973. The system assumes the interaction in an automated dispatcher network of about 900 pieces of equipment in motor vehicles (8-channel duplex radiotelephones), 120 motorcycle radiotelephones, 225 portable multichannel radiotelephones, and 6 helicopters. The system makes provision for interaction with terminal attachments, making possible the transmission of information determining the location of a vehicle or a programmed text by simply depressing a button.

Another example of a network with digital data transmission is the digital communications system in both directions between base dispatcher stations and 250 taxis in New York [8]. This system operates in the 420 MHz frequency range. Transmission of alphanumeric data is realized by the digital coding method with error correction. Transmission of information consisting of 50 words lasts about 0.5 s. In each taxi belonging to the network a small console with a display is installed (above the taximeter). The console weighs about 2.5 kg. The display comprises a panel with neon tubes and a selection system. Thirty-two different characters can be displayed. The received information can contain up to eight lines of alphanumeric text. After decoding and correction control, the received information is read into the MOS transistorized buffer memory. The memory capacity is 256 characters. Next the information is read out in sequence, line by line, and displayed on the driver's display.

The console at the dispatcher station comprises an alphanumeric keyboard, a display unit with a capacity of 32 characters, displaying the information, a buffer memory, and a system formatting and encoding the information. In addition, the dispatcher station is equipped with a CII-2200 minicomputer (32,768 words) a fast line printer, and magnetic disk memory for the purpose of storing information about each taxi. The capacity of the memory is up to 5 Mbits.

The entire New York area is subdivided into 12 zones, each of which is serviced by dispatcher stations. The vehicles have their own code numbers. The dispatcher calls automatically a taxi and records its position at a given moment and also determines whether the taxi is occupied, whether the taximeter is turned on, etc. The passenger's address is transmitted to the nearest free taxi, which directs the call by telephone to the dispatcher.

The total cost of the described communications system is over 350,000 dollars, and the cost of the base station varies (depending on equipment) from about 3000 to 100,000 dollars, and the cost of a single mobile station (when more than 100 stations are ordered) is about 1000 dollars. The Sunrise Electro-Service Corporation played a major role in the development of the system.

From the above examples it is evident that increasing efforts are being made to equip users of mobile communications dispatcher networks with technical capabilities which will allow them (besides conducting phone conversations) to transmit fast information programmed in advance or any information in alphanumeric format, and provide them a capability for direct access to departmental remote data transmission networks connected to appropriate computerized sources of information.

In the future, of course, the boundary between the digital communications systems classified above (such as the second and third kind) will be obliterated. Greatest progress in such integrated systems has been observed in the United States. Greatest "clogging" of bands assigned to mobile services occurs in the United States and, given this situation, a switch to digital communications is considered as a way out, which will prevent frequency difficulties. In addition, for many departmental services, above all, for law enforcement agencies, it is of utmost importance that mobile patrols be able to obtain immediately necessary information from appropriate files. One of the earliest systems was developed in Kansas City, when in 1965 the chief of police decided that it was necessary to develop a computerized system which was capable of delivering rapidly answers to inquiries to police patrolling the streets. As a result, the ALERT I (Automated Law Enforcement Response Team) system was developed, which was put into operation already in 1968. The system operates on an IBM 360/40 and 370/155 computer base, with IBM 3270 system CRT displays. ALERT I was expanded into the ALERT II system servicing the district attorney's office and crime prevention agencies. This system (July 1972) is using MCT-10 (Mobile Digital Communications Terminals) terminals made by the Kustom Electronics company, which provide the user (mobile subscriber) with direct access to a remote data transmission network (bypassing the dispatcher), enabling him to obtain information from a computer within 5 s. The information is displayed on a 256-character display. Data transmission is based on PSK (phase shift key) modulation, which is four times faster than conventional FSK (frequency shift keying) modulation, and practically error-free even for small signal-to-noise ratios. The high quality of MCT-10 terminals has been confirmed in practice [9].

Another communications system between mobile subscribers and remote data transmission networks is the Digitom-300 system developed by the Sylvania company. This system was tested in 1970-1971 in San Francisco, Los Angeles, New York, and Denver and has recently been introduced into operation in Oakland (California). In this system the officer can transmit not only information in digital form through a normal radiotelephone communications channel with the aid of an alphanumeric keyboard terminal; the possibility of transmitting information identifying a vehicle with simultaneous determination of its position in the terrain is also available to him. Such information is transmitted automatically after the operator simply touches the coordinate map constituting a part of the mobile communications terminal (of course the point on the map that is touched must correspond to the position of the vehicle in the terrain). Information pertaining to location appears automatically on the map in the dispatcher's station together with other information identifying the mobile subscriber [5].

Other "integrated" communications services for police and other services also exist in the United States. Each of these systems has certain advantages. A fact which deserves emphasis is the continuous modernization of these systems, one element of which is miniaturization of mobile terminals used in vehicles.

Arcom MCT-16 mobile data transmission terminals, manufactured by the Atlantic Research Corporation, equipped with a complete alphanumeric keyboard and ten additional functional keys, providing programmed access to a requested computer program in remote data transmission networks, have recently appeared on the American market. MCT-16 was designed in principle for police services; however, it can be adapted to other applications. The equipment comprises an 80-character buffer memory and a 16-character display. The received information or information that is being prepared for transmission is displayed on the display and recorded in memory. MCT-16 also comprises systems for automatic location, identification of a vehicle, automatic confirmation, automatic alarm, and switching to sound communications. The equipment can be connected to available standard radio equipment. The dimensions of the equipment are 133X292X92 mm. The equipment weighs about 2.5 kg [10].

Digital transmission of sound

Emphasis on qualitative and quantitative development of radio communications brought about the circumstance that research has been conducted for many years on increasing radiotelephone channel capacity and methods which will make it possible to narrow down their frequency bands. Generally speaking, research is being conducted in two directions. The first direction retains the analog form of the transmitted information and only strives to eliminate, optimally, the redundancy contained in a speech signal. The second direction of improving the efficiency of sound communications involves conversion of analog speech signals to discrete (digital) signals. This direction furnishes, theoretically, great possibilities for narrowing down the required frequency band. These possibilities were pointed out by Shannon.

The introduction of digital transmission of speech signals in mobile radio communications systems is difficult due to the presence of deep fading of the received signal. These fadings are a specific feature characterizing communication conditions in mobile radio communications networks. The source of these fadings is the interference character in the structure of the electromagnetic field due to multipath propagation of radio waves in the presence of barriers and the change in the position of mobile stations during communications. Particularly sharp field fluctuations occur in built-up terrain. Statistical measurements indicate that the distribution of fluctuations in amplitudes of the electromagnetic field can be well approximated by a Rayleigh distribution. Movement of a mobile station during communications gives rise to the appearance of fluctuations in the amplitude of the received signal at the output of the receiver. The frequency of amplitude changes is proportional to the carrier wave frequency and the speed of the vehicle.

These fluctuations constitute a much greater hazard for digital transmission than for normal radiotelephone transmission. The effect of fluctuations can only be reduced by special spatial diversity receiving systems. In recent years several spatial diversity receiving systems for mobile communications have been realized for experimental purposes, which made it possible to

investigate rather thoroughly the dependence of the quality of reception during digital transmission (at various types of modulation, including pulse, code, and delta modulation) on the intensity of the transmitted signal. As an example, Fig. 3 presents the transmission error rate as a function of the signal-to-noise ratio in the presence of fadings obeying a Rayleigh distribution and without fading (delta-modulation with unmodulated pulses, so-called on-off keying, and coherent detection on the receiving side) [11].

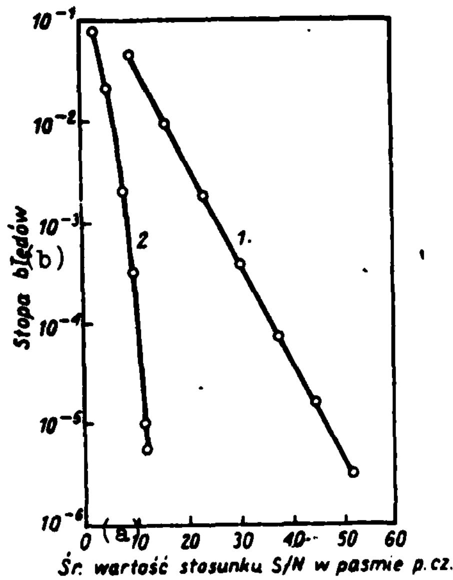

Fig. 3. Effect of electromagnetic field fadings on error rate.

1 - in the presence of fadings obeying the Rayleigh distribution

2 - without fadings

Key: a. Mean value of signal-to-noise ratio in transmitted frequency range
b. Error rate

Studies have shown that an error rate of the order of magnitude 10^{-4} is sufficient for high-quality digital transmission of speech. Without fadings this corresponds to an average value of the signal-to-noise ratio equal to

about 11.4 dB. In the presence of fadings (obeying a Rayleigh distribution), the value of the signal-to-noise ratio required to obtain the assumed error rate (10^{-4}) increases to about 37 dB. Diversity reception allows one to reduce the effect of fast fadings; therefore, it is important to ascertain the required number of diversity reception channels (multiplicity of reception) in order to obtain a result which is similar to that in which no fadings occur. Studies have shown that this is possible when the multiplicity of reception is 3-4 [11].

For practical verification of the concept of possible digital sound transmission in mobile radio communications systems, the Bell company developed an experimental radiotelephone system with digital modulation [12]. The operating frequency of the system is 836 MHz. The system consists of a base transmitting station and a mobile receiving station. Fig. 4 presents the block diagram of the transmitting station. After conversion in the encoder to a sequence of pulses, the sound signal is transmitted via a special filter to a balanced mixer, to which a continuous 24 MHz signal from the generator is transmitted. After amplification the signal from the output of the mixer is transmitted to the second mixer, generating a signal with frequency 836 MHz. This signal is amplified linearly in the power amplifier to a level of about 2 W. The antenna represents a vertical coaxial structure with a 10 dB gain with respect to the half-wave dipole.

The mobile station comprises four diversity reception channels. Fig. 5, representing the block diagram of a mobile station, shows only one channel; the remaining channels are indicated by arrows. The quarter-wave antenna supplies a balanced mixer with an intrinsic noise level on the order of 6 dB. The local 866 MHz generator supplies voltages to all channels. Voltage from the mixer is fed to the amplifier (amplification gain about 55 dB and 1.5 dB noise factor). This is followed by the quartz filter with 100 kHz bandwidth. The diode system operating as a square law detector follows the filter and amplifier from the automatic gain control system. The output of detectors from all channels are parallel and connected to the adder input. The signal at the output from the adder is separated into two parts: the first part is fed to the

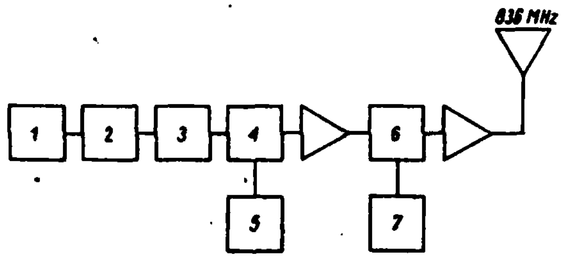

Fig. 4. Block diagram of receiver in digital sound transmission base station:

1 - tape recorder 2 - encoder 3 - cosine wave filter 4,6 - mixers 5 - 24 MHz generator 7 - 860 MHz generator

low bandpass filter controlling the automatic amplification gain system of the amplifier and the second part is fed to the decoder. A magnetic tape memory system constitutes the output of the decoder.

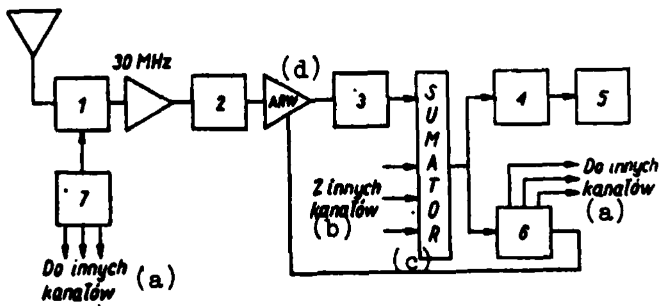

Fig. 5. Block diagram of receiver in mobile digital sound transmission station:

1 - mixer 2,6 - filters 3 - square law detector 4 - decoder 5 - tape recorder 7 - 866 MHz generator

Key: a. To other channels b. From other channels c. Adder d. Automatic gain control

The system was tested both under laboratory conditions using a fading simulator, as well as under field conditions. The field tests were conducted

under large city conditions and in the suburbs. The tests involved calculating the average frequencies of occurrence of interferences (clicks) in the acoustic band of the receiver as a function of the signal power and multiplicity of diversity reception. The simulator used in the laboratory tests generated several independent signal pulse trains with amplitude fluctuations the values of which corresponded to a Rayleigh probability distribution varying over time by 40 dB. The frequency of fadings of signals from the simulator was equivalent to a 60 mph car speed and a wave with frequency 836 MHz.

The conducted tests demonstrated that a one-channel system is unsuitable from a practical standpoint and that a two-channel system is inadequate. On the other hand, three- and four-channel systems operate quite efficiently.

Tests in the suburbs covered an area built up with villas. The base station was placed on the peak of an elevation at a height of about 75 m above the terrain, and the antenna was placed at the top of an 18 m long mast. The power of the transmitter was varied from about 2 W to 2 mW. The mobile station was placed in a van traveling at average speed in the tested region. Antennas in the form of quarter-wave rods were placed on the van roof. The antenna spacing was about 0.75 times the wavelength. The test signal was based on the read text of a technical article prepared specially for the tests. Measurements of the intensity of the field were conducted simultaneously with reception of the sound signal. Generally, the system operated in the suburb area similarly as under laboratory conditions.

The built-up terrain was characterized by tall, isolated skyscrapers and narrow streets. The base station with an antenna with a 4 dB gain was placed on the roof of a skyscraper. The mobile station was identical to that used in suburb tests. Generally, the quality (intelligibility) of the received speech signal was very good during three- and four-channel reception. However, sporadic cases of a drop in the output signal level were noted in the presence of an input signal, the value of which remained above the threshold. A possible cause of this may have been interferences originating from the operation of other pulse systems, or time delays during multipath propagation of the station's

own signals. The field tests demonstrated that digital modulation can be used under multipath propagation conditions, which occurs in areas covered by mobile communications.

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